Grounding Separate Structures

John Wiles

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In many stand-alone PV installations, the main ac loads for the system are located in a building or structure separate from the PV array, batteries, and the inverter. This poses the question: "How is the ac system grounded to meet the requirements of the National Electrical Code?"

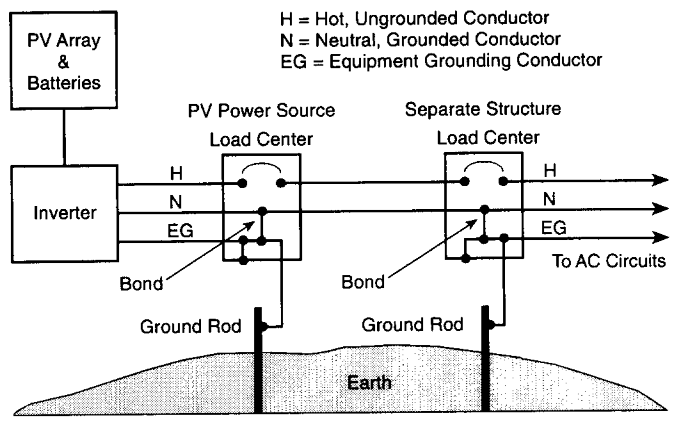
The general requirements for grounding were covered in the Code Corner column in *HP* 64 for a system where all of the sources and loads were in the same building. In this article, the requirements for grounding the ac circuits running to separate structures will be covered. In general, where the loads are some distance from the source, it is best to group the low-voltage circuits (PV, batteries, and inverter) in one location and then run the 120-volt or 120/240-volt output of the inverter to the loads at the separate structure. This configuration will minimize losses in the cables since the 120-volt ac circuits operate at lower currents than the low-voltage DC circuits. There are two accepted methods of grounding the ac circuits leading to separate structures.

Common to both methods is the requirement for a grounding electrode (e.g., a ground rod) at each structure—both the PV power source building and the structure (residence) where the distant loads are located. Grounding electrodes in both locations are required to serve as a grounding system for the equipment-grounding conductors at each location. As discussed in *HP* 64, all exposed conductive (metal) surfaces in the power system must be connected together with the appropriately sized conductors and then connected to a grounding electrode.

Method 1

The first method of grounding the separate structure is similar to the grounding used in a grid-connected home for grounding the service entrance conductors.

At the PV/inverter location, there is a bond or connection between the ac neutral conductor on the output circuit of the inverter and the grounding system leading to the grounding electrode. This bond is usually made in the load center or circuit breaker box that is used to provide overcurrent protection for the inverter output.

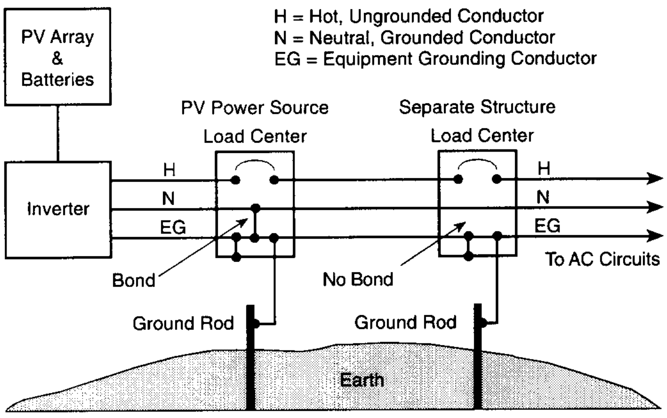


Only the ungrounded (hot) and neutral ac conductors are run to the separate structure. The equipment-grounding conductor (bare or green wire) is not connected between the two locations. In a 120-volt system, there will be only two conductors (one hot and one neutral) connected between the two locations. In a 120/240-volt system, there will be three conductors (two hot and one neutral) connected between the two systems. The two grounding electrodes must not be connected together by a separate bonding conductor.

At the separate structure, the neutral conductor is again bonded or connected to the grounding system. As mentioned above, this is identical to utility practice where the neutral service entrance conductor is bonded to ground at the utility transformer and again at the residential load center. Only ungrounded (hot) and neutral conductors are brought to the house.

Method 2

In the second method, the neutral conductor is bonded to the grounding system at the inverter location, but is not bonded to the grounding system at the separate structure. A separate, isolated (insulated) bus bar is required so the neutral conductors can be isolated from the grounding system. In this method, shown in Figure 2, an equipment-grounding conductor is connected between the two locations and run along with the hot and neutral conductors. In a 120-volt system, there will be three conductors between the two locations (hot, neutral, and equipment-grounding). In a 120/240-volt system there will be four conductors between the two locations (two hot, one neutral, and one equipment-grounding).



Sizing the Equipment-Grounding Conductor
The equipment-grounding conductor should be sized according to the requirements of Table 250-95 in the NEC, which is based on the overcurrent device protecting the circuit. For example, if the circuit overcurrent device is 60 amps, the equipment-grounding conductor should be a number 10 AWG (American Wire Gauge) copper conductor. If the circuit is a 100-amp circuit, then the equipment-grounding conductor should be a number 8 AWG copper conductor.

Changes Required for Voltage Drop
Since the distances between the inverter location and the building with the loads may be significant, many installations use oversized hot and neutral conductors to reduce the voltage drop between the two locations. To ensure proper operation of overcurrent devices in this instance, Section 250-95 of the NEC requires that the equipment-grounding conductor be oversized proportionally.

For example: A Trace SW4024 4000-watt inverter has the 60-amp ac output connected to a circuit which is protected with an 80-amp circuit breaker. From ampacity calculations (NEC Table 310-16), a number 4 AWG conductor with 75°C insulation is selected with an ampacity of 85 amps at 30°C ambient temperature. The use of an 80-amp circuit breaker, providing overcurrent protection for this conductor, would dictate a number 8 AWG equipment-grounding conductor. A very long distance between the inverter and the house results in excessive voltage drop on even this 120-volt circuit. Voltage-drop calculations indicate that the conductors (hot and neutral) should be increased in size to number 1 AWG conductors.

Table 8 in Chapter 9 of the NEC is used to find the cross-sectional areas of each of the conductor sizes. They are: 8 AWG = 16,500 circular mils(cir mil), 4 AWG = 41,740 cir mil, 1 AWG = 83,690 cir mil.

The ratio of areas between the new number 1 AWG conductor and the original number 4 AWG conductor is 83,690/41,740=2.005. The NEC requires that the equipment-grounding conductor be increased in size by this factor of 2.0. The calculation shows that the new area is 2.005 x 16,500 = 33,083 cir mil which, from Table 8-Chapter 9, is a number 4 AWG cable.

The circuit now has two number 1 AWG conductors (hot and neutral) and a number 4 AWG equipment-grounding conductor.

Additional Requirements for the Equipment-Grounding Conductor
The equipment-grounding conductor may be bare (no insulation) or have green insulation. For sizes larger than number 6 AWG, only black-insulated conductors are generally available, so the NEC allows these conductors to have the exposed insulation marked with a green tape at each termination and at other places where the cable is accessible.

For ac circuits, the equipment-grounding conductor must be run in the same cable, conduit, or raceway as the current-carrying conductors.

An Aside for DC circuits
The same procedure for oversizing equipment-grounding conductors for voltage-drop considerations in ac circuits can be used for DC circuits.

Summary
In stand-alone PV systems, where the ac load circuits are some distance from the ac source (the inverter) in separate buildings or structures, there are two options for correctly grounding the system. Of the two grounding methods presented in this article, the first method uses one less conductor and is therefore less expensive. Other design considerations, such as using oversized conductors to reduce voltage drop and losses, require that the equipment-grounding conductor also be oversized.

Questions or Comments?
If you have questions about the NEC or the implementation of PV systems following the requirements of the NEC, feel free to call, fax, email, or write me at the location below. Sandia National Laboratories sponsors my activities in this area as a support function to the PV Industry. This work was supported by the United States Department of Energy under Contract DE-AC04-94AL8500. Sandia is a multi-program laboratory operated by Sandia Corporation, a

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Author: John C. Wiles, Southwest Technology Development Institute, New Mexico State University, Box 30,001/ MSC 3 SOLAR, Las Cruces, NM 88003
Phone 505-646-6105 • FAX 505-646-3841
email: jwiles@nmsu.edu

Sandia National Laboratories Sponsor: Ward Bower, Sandia National Laboratories, Division 6218, MS 0753, Albuquerque, NM 87185 • 505-844-5206
email: wibower@sandia.gov

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